ELECTROCARDIOGRAM SIGNAL ANALYSIS: A REVIEW

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Abstract **- Electrocardiogram (ECG) signal is vital information to diagnose cardiac diseases. A wide range of cardiac disorders can be diagnosed by analyzing it. But it gets highly affected by different noise interferences and artifacts during its recording which alters the original signal. These noise and interference are strong enough to suppress the clinically important features related to the small amplitude. It is essential to remove the noise for efficient analysis of ECG which is the followed by the extraction of the required cardiac parameters. This paper discusses different techniques that have been used in ECG signal analysis and their implementation in a wide variety of systems in recent research work.**

Keywords- **Electrocardiogram (ECG), Artifacts, Filtering, Hardware Description Language (HDL)**

I. INTRODUCTION

The electrocardiogram (ECG) signal is the graph showing the variation of bioelectric potential with respect to time as the human heart beats. It provides valuable information about the functional aspects of the heart and cardiovascular system. There is numerous research works in the field of analyzing ECG signals. The main tasks in ECG signal analysis are the detection of QRS complex and the estimation of instantaneous heart rate [17].

Any ECG gives two kinds of information:

1. The duration of the electrical wave crossing the heart which in turn decides whether the electrical activity is normal or slow or irregular and
2. The amount of electrical activity passing through the heart muscle which enables to find whether the parts of the heart are too large or overworked. [1]

Significant features of ECG waveform: Figure 1 shows the typical ECG waveform, characterized by five peaks and valleys labeled by the letters P, Q, R, S, T. In some cases, another peak called U is also used.

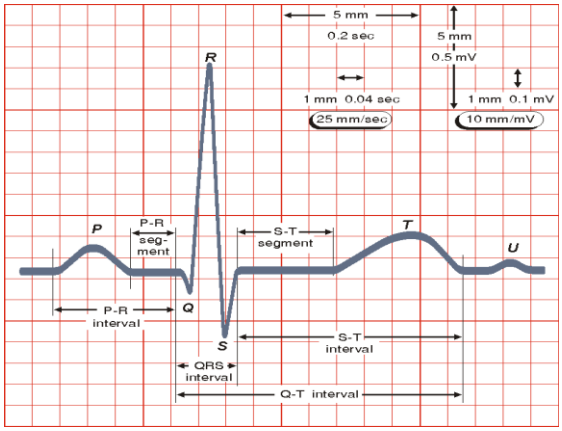

Figure 1: Typical ECG Waveform (Google Images)

The P wave reflects the sequential activation (depolarization) of the right and left atria.

The Q, R, and S waves are treated as a single composite wave known as the QRS complex. It indicates depolarization of the right and left ventricles of the human heart. The T wave reflects ventricular repolarization. A small U wave is normally visible in 50 to 75% of ECGs. [7]

The deviations in the normal electrical patterns indicate various cardiac disorders that may occur due to many reasons. The ECG gets corrupted due to various kinds of the artifacts.

1. EMG signal (muscle contraction)
2. Power line interference
3. Electrode contact noise
4. Motion artifacts
5. Baseline drift and ECG amplitude modulation with respiration
6. Instrumentation noise generated by electronic devices used in signal processing
7. Electrosurgical noise [14]
8. Electroencephalogram (EEG)
9. Bad electrodes and improper electrode site preparation.

As original ECG signal contains various type of noise leading to false detection of the QRS complex which is not desired, so it is very essential to filter the noise signal from the ECG signal and efficiently detect the QRS complex.[12]

II. LITERATURE SURVEY

Different researchers have worked on noise removal or reduction in ECG and its analysis.

Earlier research work on ECG show that some research has been done on noise sensitivity while some on QRS detection. Different algorithms have been proposed for noise sensitivity and QRS detection. However, no research work was done taking both the cases together. But since past few years, research in this area is in fast pace in order to develop an efficient method for ECG signal analysis.

In 2009, Suranai Poungponsri et. al have used wavelet neural network (WNN) to study ECG signal modeling and noise reduction.WNN combines the multi-resolution nature of wavelets and the adaptive learning ability of artificial neural networks[19].

In 2010, Zainab N. Ghanim have used VHDL program to build Slantlet Transform for the feature extraction of ECG monitoring and Diagnosis system which converts the continuous ECG signal to a form that can be classified by a classifier of the ECG monitoring and Diagnosis system to detect the cardiac abnormalities [20]. Rakesh Chand et. al presented the design of FIR filter to remove EMG from ECG signal using the branched tree architecture for adder connection to reduce the critical delay. The Proposed architecture has been implemented on FPGA using Verilog Hardware Description Language (HDL).Since coefficient

quantization technique is used, so this implementation consumes lesser area that reduces the Hardware required. [12]

In 2011, Seema rani et. al worked on the comparison of Digital FIR & IIR filter complexity and their performances to remove baseline noises from the ECG signal. FIR equiripple filter, windowing FIR filters with Kaiser, Rectangular, Hamming, Hanning and Blackman functions and four IIR filters i.e. Butterworth filter, Chebyshev Type I, Chebyshev Type II and Elliptic filter are designed. In the design process of IIR filters, filter order is only 2.The two important parameters to check the suppression of Baseline noises, which are Spectral density and Average Power of signal, are calculated. The results shows that fall in value of spectral density after filtering is very large in case of FIR equiripple filter. Kaiser window and rectangular window show better results. But in case of remaining windows i.e. Hamming, Hanning and Blackman windows, the order of filter grows very much high. It increases the number of filter coefficients which leads to the large memory requirement and problems in hardware implementation. The computational complexity of FIR filter is far greater than IIR filters [4].

Mbachu C.B et. al presented the work which consisted of the design of FIR digital filters with Kaiser Window to remove the interferences or the artifacts. Three filters are considered: low pass, high pass and notch filters. Each filter is used to filter the raw noisy ECG signal after which the three filters are used in cascade. Matlab is used for the design. Results for each filter are observed and also for the case when all three filters are in cascade. When the raw ECG signal is filtered with the three filters in cascade, the certain amount of noise was removed, producing a near clean ECG signal. However, the design of the filters indicates that there are some ripples in the filters but the responses are stable [5].

Manish Kansal et. al designed equiripple Linear phase IIR filter using the Parks-McClellan Algorithm to calculate the coefficients. This algorithm gives the minimum order filter for the given specifications. The design was done first in MATLAB in order to check the feasibility of the specifications in MATLAB and then in VHDL and simulated in Modelsim software. After checking the filtered output, the delay between the input signal and the output signal was calculated from the Modelsim wave window. It was found that the delay between FSCLK and MCLK is 6.5 ns and delay between input and output signal is 998396.5 ns. Various blocks are used in architecture of Digital IIR filter such as multipliers, adders, flip flops. Number of adders, multipliers is very less in IIR as compare to FIR.[6]

In 2012, Sagar Singh Rathore et. al have used wavelet technique for analysis of ECG signal using MATLAB software. Daubechis 10 Wavelet is used for analysis of ECG signal up to detail level 5. Result state that Wavelet Transform Technique gives good frequency & time information of ECG signal because it is easy to identify & locate the changes in pathological conditions of ECG signal. Some abnormalities were found by researchers in this process. [10].

Md.Tarek Uz Zaman et. al. discussed different de-noising methods to eliminate noise from the ECG signal. Three techniques are used for de-noising i.e. using Notch filter, Sgolay filter and Wavelet. Among all existing methods, Sgolay filter performed better than the other existing method [12].

R.Sivakumar et. al used many filters for noise removal & noise removed signal is given for analysis such as stress in the patient. The performance measures such as PSNR (Peak Signal to Noise Ratio) is calculated and determined. PSNR values are used to find the appropriate filter which gets extended with Empirical Mode Decomposition and Wavelet Decomposition to determine the stress in the ECG signal. The method involves the extraction of the required cardiac components by rejecting the background noise with the help of filtering technique. The simulation is done in MATLAB environment. Results show that Haar wavelet transform is the best method to de-noise the noisy ECG signals.[13]

In 2013, Digvijay J. Pawar et. al research work was based on High pass filtering of ECG signal to remove baseline wander while preserving the low frequency ECG clinical information. The results of different filter design techniques like equiripple, least square and various windowing methods are compared using MATLAB simulation tool and best suited technique is used for further implementation on FPGA platform. The two important parameters, Spectral density and Average Power, of signal are used to check the suppression of Baseline noises. In order to measure the performance of de -noising, SNR of processed ECG is calculated. Least Square method gives more improved output SNR with minimum order design [14].

Kiran Kumar Jembula et. al used an algorithm which makes use of the linear quadrature mirror filter (QMF) B-spline wavelet for the detection of QRS complex. The Wavelet coefficient corresponds to a measurement of the ECG components in the time segment and frequency band. The generated source has been simulated for validation and tested on software Verilogger Pro6.5. The maximum throughput obtained was 52.67 MSamples/sec. The data output was also compared with MATLAB output [17].

Ankit Jayant et. al presented different approaches for performing baseline noise removal in the electrocardiogram (ECG) signal which includes methods based on use of project pursuit gradient ascent, cubic spline curve fitting, linear spline curve fitting, median filters, digital filters, adaptive filters, wavelet adaptive filters and empirical mode decomposition. Each technique has certain advantages and disadvantages. However, according to the researchers, Wavelet adaptive filter is the recommended approach for baseline removal for the analysis of ST segment deviations in the ECG.[29]

Sonu Bittoliya et. al have designed median filter using artificial neural network (ANN), for removal of Baseline wander noise. A moving median filter smoothes data by replacing each data point with the median of the neighboring data point defined with in the span. Previous studies has shown that the neural network based method present effective approaches for denoising of ECG signal but there is insufficient research in the area of automated calculation of cut-off frequencies. This paper presented application of ANN to identify the cut-off frequency for removal of the high frequency noise in ECG signal. All the signals are transformed to frequency domain using Fast Fourier Transform (FFT). [19]

Khalifa Elmansouri et. al proposed implementing the UWT (Undecimated Wavelet Transform) method to realize a de-noising method. Experiment was done regarding signal to noise ratio (SNR).The UWT is redundant, linear, shift invariant, more robust and less sensitive to noise. This method first finds zero-crossings among the coefficients with coarse resolution and then finds zero-crossings among the coefficients with finer resolution. Finding zero-crosses among the coefficients with coarse resolution enables to remove noise from a signal efficiently. Finding zero-crossings among the coefficients with finer resolution improves the precision with which peak locations can be found. An adaptive threshold selection using principle of Stein's Unbiased Risk

Estimator is used to calculate the threshold value. Then, soft thresholding is used to remove the noise. Finally, the noise-free ECG is obtained by taking the inverse UWT. [20]

In 2014, Mohamed Egila et. al used Least-Square Linear Phase FIR filtering denoising methodology to suppress baseline wander noise. Feed forward neural network methodology is used as the classifier to analyze the ECG signal from the myocardium. Discrete Wavelet Transform (DWT) is employed as a feature extraction tool to achieve efficient design to classify as normal beat or abnormal beat, but due to use of neural network, complexity has increased significantly [21].

Nakul Nagpal et. al described the implementation of a potentially effective QRS detection algorithm that incorporates a slope vector waveform analysis. It allows for a fast and accurate search of the location of the peak of the R wave, QRS complex duration. This method is computationally involved and generates significant redundancy which represents a disadvantage that restricts its application in embedded real-time systems.[6]

Isha V Upganlawar et. al dealt with the study of Median filtering and FIR(Finite Impulse Response) filtering of ECG signals under noisy condition. Matlab functions were used for the study. For noise removal Matlab function 'smooth ()' is used. The function uses the average filter and FIR (Finite Impulse Response) Filter for smoothing the ECG signal. This combination of FIR and moving average filter in preprocessing an ECG signal removes not only baseline drift (drift refers to the deviation of the signal from one state to another unpredictable state) but also preserves edges while removing noise. [23]

Rupali Madhukar Narsale et. al suggested Design of low power FIR Equiripple Notch type -1 filter using the direct-form approach for the removal of power line interference in ECG signal. This approach gives a better performance than the common filter structures in terms of speed of operation, cost, and power consumption in real-time. An Equiripple or Remez Exchange (Parks-McClellan) design technique provides an alternative to windowing by allowing the designer to achieve the desired frequency response with the fewest number of coefficients using an iterative process. This process involves comparing a selected coefficient set to the actual frequency response specified until the solution is obtained that requires the fewest number of coefficients. The filter is first designed in MATLAB in order to check the feasibility of the specifications, then in VHDL. The simulation is done in Modelsim software after that burned on FPGA kit to get the utilization information. The minimum power achieved is 0.073w in FIR filter and used 626 taps, 8 bits input. The results of the implementation show that filter removed the noise specifically meant for it [24]. I. Kaur et al.(2016) made use of discrete wavelet transform to detect the QRS complex and arrhythmia and achieved an error rate of 0.221%[25].

T. Debnath et al. worked on the calculation of heart rate and detection of tachycardia, bradycardia, asystole and second degree AV block from detected QRS peaks using MATLAB. The final task is to classify the heart abnormalities according to previous extracted features. The back propagation (BP) trained feed-forward neural network has been employed to classify the heart abnormalities[26].

In 2017, Birendra Biswal applied modified s-transform on the denoised ECG signal to detect QRS complex and obtained 99.77% accuracy [27].

Matteo D'Aloia et al. (2018) presented an effective approach for peak point detection and localization in noisy electrocardiogram (ECG) signals. Implementation has been done in six stages method, which adopts the Hilbert transform and a thresholding technique for the detection of zones inside the ECG signal. The analysis of identified zones is done by wavelet transform for R point detection and localization. They worked on challenging and most distorted signals and achieved results with minimal interference for a signal to noise ratio of 6 dB[28].

III. CONCLUSION

Artifacts in ECG monitoring can be annoying and dangerous in accurate detection of cardiac disorders. An understanding of the sources of artifact and care can significantly reduce or even eliminate the problem. Inspite of various methods of noise removal and accurate detection, no method is found efficient that can be applied for all kinds of artifacts of ECG signal. There is a need for the robust method for ECG artifact removal and accurate detection of QRS complex.

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